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The Argus Experiment

The following report is based primarily on papers presented at the Symposium on Scientific Effects of Artificially Introduced Radiations at High Altitudes, held at the National Academy of Sciences, Washington, D. C., on April 29, 1959. The papers, which appeared in complete form in the August 1959 issues of both the Proceedings of the National Academy of Sciences (*reprinted also as* IGY Satellite Report Series No. 9, *September 1959*) *and the* Journal of Geophysical Research, *were, in the order of their presentation, read by Richard W. Porter of the General Electric Company, Nicholas Christofilos of the University of California, James A. Van Allen of the State University of Iowa, Major Lew Allen, Jr., and Captain Joseph A. Welch, Jr., of Kirtland Air Force Base, New Mexico, Philip Newman of the Air Force Cambridge Research Center, and Allen M. Peterson of Stanford University.*

Although the Argus Experiment was not part of the Program, and neither the USNC-IGY nor the National Academy of Sciences was instrumental in its planning and conduct, an IGY satellite made many observations of Argus phenomena. Moreover, Argus data relate to upper-atmosphere work investigated in IGY programs. Hence, the experiment appeared to be of sufficient interest to IGY scientists to warrant this summary report in the Bulletin.

Equipment for measuring cosmic-ray intensity at high altitudes, carried in US-IGY satellite 1958 Alpha (Explorer I), first discovered the existence of high-intensity radiation—the Van Allen radiation regions—trapped in the earth's magnetic field. (In this report, the term "radiation" in general refers to charged particles.) Further investigations with 1958 Gamma and 1958 Epsilon (Explorers III and IV, respectively) and with the US-IGY deep-space probes, Pioneers I, III, and IV, increased knowledge of the nature of the radiation and its extent in space. (*See Bulletin No. 21.*)

The manner in which charged particles are trapped in the earth's magnetic field has been long understood through the work of C. Stoermer, H. Alfven, and others. This theory was confirmed by the satellite and space-probe observations mentioned above.

In October 1957, a few months before the launching of 1958 Alpha, N. C. Christofilos, of the University of California's Lawrence Radiation Laboratory, noted that many observable geophysical effects could be produced by small-yield atomic detonations in the earth's tenuous upper atmosphere.

It was believed by Christofilos and upper-atmosphere physicists to whom the idea was communicated, that artificial, impulsive injection of known particles along known magnetic lines of force, at a known time would constitute a powerful technique for clarifying uncertainties of the dynamics of geomagnetic trapping as well as for studying related geophysical effects. The

natural radiation trapped in the Van Allen regions could not, of course, be subjected to such experimental control.

Theory: According to the trapping theory, an electron injected at high altitude into the earth's magnetic field, which closely resembles that of a bar magnet, would spiral in a helical pattern about a magnetic line of force (see Fig. 1). Since the field

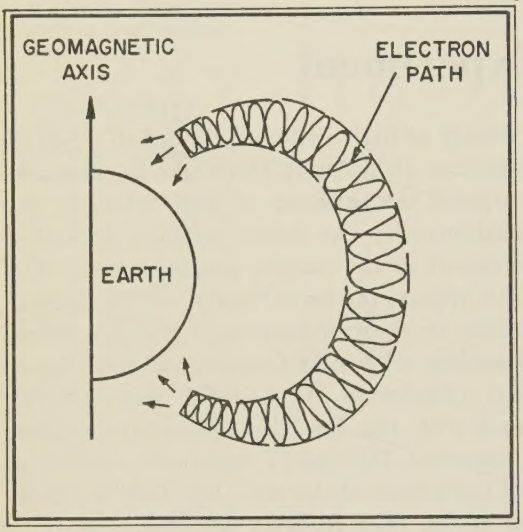

FIG. 1. *Schematic Diagram of Path of Electron in the Earth's Magnetic Field. (Actual path is very much narrower and describes innumerable tight spirals.) Angular distributions at the mirror points form disc-like patterns. Most electron losses occur by scattering in the denser atmosphere near the mirror points.*

strength increases toward the earth, the particle would finally reach a point near the end of the line of force, but still at considerable height, beyond which it could not penetrate. These points, one of which exists for each particle at each end of the line of force about which it spirals, have been termed "mirror points" since they cause the particle to be reflected back along its course. This process continues at great speed until the particle is finally "lost," usually in the vicinity of the mirror points, through repeated collisions with molecules of the earth's atmosphere.

In addition to the motions described above, trapped electrons would drift eastward around the earth owing to the de crease in strength of the magnetic fiel with altitude, the centrifugal force of th spiraling particles, and certain other fac tors. Hence, if a sufficiently large volum of electrons were injected into the magneti field at a single point, the combined motion would result in the formation of a thin she of electrons completely encircling the eart and bounded approximately by the mag netic lines of force between which the par ticles were injected.

The lifetime of an electron trapped i the magnetic field is directly proportiona to the length of the line of force abou which it spirals and approximately to th square of the electron's energy, and in versely proportional to the air density a the mirror points. Injected electrons woul be scattered out of their initial spiral tra jectories by collisions with air particle and, since the density of the atmospher decreases exponentially with increase of al titude, such collisions would occur wit greatest frequency near the mirror point in the lower portions of the electron paths Hence, most electron losses would occu near the mirror points. The scattering re sults in further lowering of the mirror point into regions of still greater density. It wa expected that most electrons with energie of 1-2 million electron volts (mev) injecte at an altitude of a few hundred kilometer would survive for several hours or more.

In addition to the trapping effect, the cre ation of an artificial aurora at each en of the lines of force passing through th detonation region was predicted. Electron from the detonation would be guided alon these lines of force in both directions, ioniz ing the air through which they passed an also causing auroral luminescence at bot points where the lines of force re-enter th denser atmosphere. It was also expecte that certain magnetic, electromagnetic, an ionospheric effects would be observable.

Organization of Experiment: After pre liminary calculations had been made b

Christofilos, a proposal for a series of studies based on the artificial injection of electrons into the magnetic field at high altitudes by small-yield nuclear detonations was presented to the President's Science Advisory Committee. At the suggestion of this committee, a group of representatives of both the scientific and military communities (since the experiments involved the interests of both) was formed to appraise all aspects of the undertaking. By this time, the IGY satellite experiments designed by James A. Van Allen of the State University of Iowa had partially confirmed the trapping theory. Therefore, it was decided late in April 1958 to proceed with the artificial-injection experiment, which was given the code name of "Argus." Overall responsibility for the preparation and conduct of the Argus Experiment was given to the Advanced Research Projects Agency (ARPA) of the Department of Defense. Herbert York, then Chief Scientist for ARPA, directed the program.

Since the magnetic axis of the earth is tilted with respect to the axis of rotation and the center of the magnetic dipole is displaced toward the Pacific Ocean, it was apparent that the mirror points would be closest to the earth's surface over the South Atlantic. Hence, this region was selected for the high-altitude detonations. This location also afforded conjugate, or mirror, points near the Azores Islands in the North Atlantic, making it easier to conduct observations of the aurora expected to occur at that end of the line of force.

The mission of delivering three small-yield nuclear devices to high altitude over the South Atlantic and detonating them was undertaken by a US Navy task force specially organized for this purpose. The three nuclear devices were detonated in late August and early September 1958, all at a nominal altitude of 480 kilometers (about 300 miles). They were delivered to their detonation points in the upper atmosphere by multi-stage rockets launched from the *USS Norton Sound*. The first burst occurred at approximately 0230 UT, August 27, at a geographic location of approximately 38°S, 12°W; the second was at about 0320 UT, August 30, near 50°S, 8°W; and the third was on September 6, at about 2210 UT, and in the vicinity of 50° S, 10°W. The position of the shells of trapped Argus electrons relative to the Van Allen regions of trapped natural radiation is shown in Figure 2.

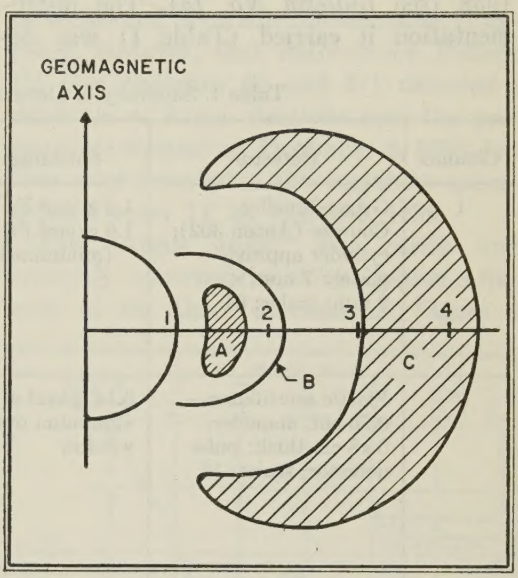

Fig. 2. *Approximate Position of Argus Shells with Respect to the Van Allen Regions of Trapped Natural Radiation. A is the inner Van Allen belt; B is the position of the Argus shells; and C is the outer Van Allen belt. Scale in earth radii.*

Two IGY satellites, Explorer IV (1958 Epsilon) and Explorer V, contained instrumentation designed at the State University of Iowa to measure the natural radiation in the Van Allen belts. This instrumentation was also capable of measuring the artificial radiation in the Argus shells. (Explorer V did not go into orbit.) The Air Force Special Weapons Center prepared a series of high-altitude sounding rockets to study the lower fringes of the radiation shells (Project Jason). Stanford Research Institute and the Air Force Cambridge Research Center developed and installed at various ground locations and aboard aircraft and ships a

variety of equipment to measure the expected auroral, radio, magnetic, and electromagnetic effects. The following material reviews the aims, techniques, and preliminary results of the various investigations related to the Argus Experiment.

Satellite Observations

1958 Epsilon entered an orbit inclined at 51° to the equator at 1506 UT, July 26, 1958 (see *Bulletin No. 15*). The instrumentation it carried (Table 1) was designed under the direction of James A. Van Allen, Carl E. McIlwain, and George H. Ludwig, all of SUI.

The location in space of the magnetic shells created by the experiment was chosen so that the shells could be intercepted by a relatively low-altitude satellite with a orbital inclination not greater than 51°, th highest inclination practical with the avail able facilities. The intermediate latitud chosen for the detonations also permitte the satellite orbit to intercept the shells c trapped particles at a less oblique angl Moreover, since the measurements of Ex plorers I and III had shown a rapid de crease with distance from the magneti equator in the intensity of the natural radi ation at a given altitude, the "backgroundi radiation was expected to be less at inter mediate latitudes than at lower latitudes.

Table 1. Summary of Detector Characteristics (Explorer IV)

Channel	Detector	Shielding	Sensitive to:	Geometric Factor
1	Geiger-Mueller Counter (Anton 302); cylinder approximately 7 mm × 9 mm; scaler: 64	1.2 g/cm² Fe + 1.6 g/cm² Pb (minimum)	Electrons of $E >$ 5 mev; protons of $E >$ 40 mev; X-rays of $E >$ 80 kev, with low efficiency	Omnidirectional geometric factor 0.14 cm² for minimum stopping power; 0.82 cm² for penetrability greater than 7 g/cm²
2	Plastic scintillator—0.76 cm. diameter, 0.18 cm thick; pulse detector; scaler: 16	0.14 g/cm² of aluminum over window	Electrons of $E >$ 580 kev; protons of $E >$ 10 mev; axis of detector ⊥ to payload axis; X-rays of $E >$ 300 kev, with low efficiency	0.040 cm² steradian for minimum stopping power; 4.2 cm² steradian for penetrability greater than 5 g/cm²
3	Same as Channel 1 except less shielding; scaler: 2048	1.2 g/cm² Fe (minimum)	Electrons of $E >$ 3 mev; protons of $E >$ 30 mev; X-rays of $E >$ 20 kev, with low efficiency	Omnidirectional geometric factor 0.14 cm² for min. stopping power; 0.70 cm² for greater than 5 g/cm² stopping power
4	Cesium Iodide crystal — 0.76 cm diameter, 0.20 cm thick; total energy-d.c. electrometer	1.0 mg/cm² of nickel and aluminum over window	Electrons of $E >$ 20 kev; protons of $E >$ 400 kev; X-rays; axis of detector ⊥ to payload axis	0.0235 cm² steradian for minimum stopping power; 4.4 cm² steradian for penetrability greater than 5 g/cm²
5	Same as 2 except scaler: 2048			

Nature and Scope: In the month befor Argus I, 1958 Epsilon collected muc data serving to establish the detailed spa

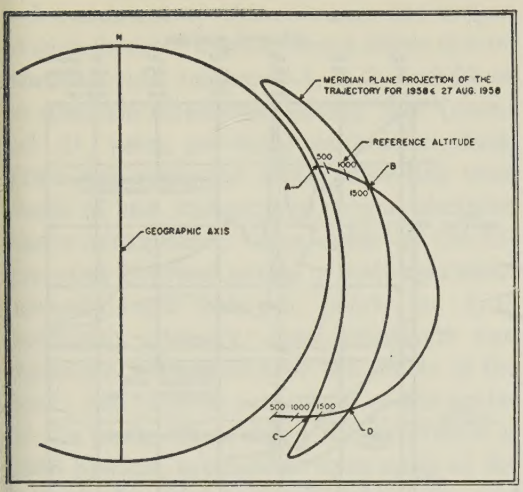

Fig. 3. *Typical Geometric Relationships Between 1958 Epsilon Orbit and Argus Shells. A, B, C, and D represent points of intersection; reference altitudes are in kilometers.*

tial relationships and many of the properties of the natural trapped radiation. Between August 27 and September 19, significant data were obtained on 164 intersections of the Argus shells by 1958 Epsilon. Most of the observed intersections occurred in the northern hemisphere, where tracking facilities are more complete.

Typical geometric relationships between the satellite orbit and the shell of magnetically trapped radiation are shown schematically in Figure 3. It can be seen that ideally the shell is intersected four times, at various altitudes, latitudes, and longitudes, during a satellite revolution. Actually, however, significant data were obtained on an average of much less than four intersections per orbit owing to the low altitude, and hence the low electron intensity, of many intersections; distortion and tilt of the magnetic shell, so that fewer than four intersections occurred on some orbits; occurrence of some intersections beyond radiotelemetry range of the receiving stations; and occurrence of some intersections at points where the intensity of artificial radiation was smaller than that of the natural radiation (this condition prevailed everywhere along the satellite orbit after each artificial-radiation shell had decayed with time to a certain degree).

The lower-powered of the two transmitters and telemetry channels 2 and 5 were exhausted on about September 3. The higher-powered transmitter and channels 1, 3, and 4 operated properly until about September 21. By this time the Argus III particles were still being detected above the background radiation, but only on occasional favorable intersections. It appears, however, that space-probe Pioneer III (see *Bulletins 20 and 21*) detected a residuum of Argus electrons near the geomagnetic equator on December 6, 1958, but none were detected in this region by space-probe Pioneer IV on March 3, 1959.

The "Argus effect" was easily and promptly observed by 1958 Epsilon after each of the three detonations. Figure 4

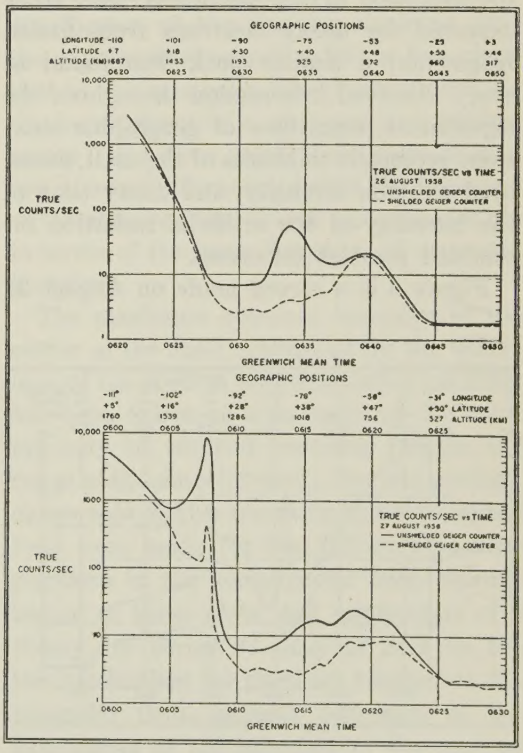

Fig. 4. *Comparison of Counting Rates the Day Before Argus I (upper graph) and a Few Hours After Argus I. The peak at 0608 UT on the lower graph represents intersection of the electron shell by 1958 Epsilon.*

shows a record of measurements of the natural radiation taken the day before Argus I (upper graph), and a record taken through a similar geographic region about 3½ hours after the Argus I detonation (lower graph). Nothing equivalent to the great peak intersected at 0608 UT, August 27, had been observed by 1958 Epsilon during the preceding four weeks. Moreover, the peak was encountered on the first observed intersection with the planned magnetic shell following the Argus I burst. During the entire active period of 1958 Epsilon (July 26-September 21, 1958) no such peaks were observed except those corresponding in time and place to the expected artificial radiation.

Further reasons for identifying these peaks with the Argus effect are: the observed energy spectrum and the nature of the radiation agreed essentially with those expected for decay electrons from fission fragments; a similar peak was found at every observed intersection throughout the experiment, regardless of geographic location; geometric thickness of the shell, measured electron intensity, and decay time of the intensity of the artificial radiation resembled pre-test estimates.

Figure 5 is a record made on August 31

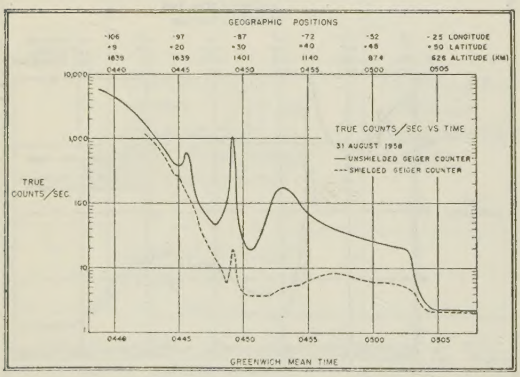

Fig. 5. *Counting Rate Record Showing Fresh Argus II Peak and Decaying Argus I Peak. Large peak at 0449 UT represents satellite intersection of Argus II shell; small peak three minutes earlier is intersection of remnant of Argus I shell.*

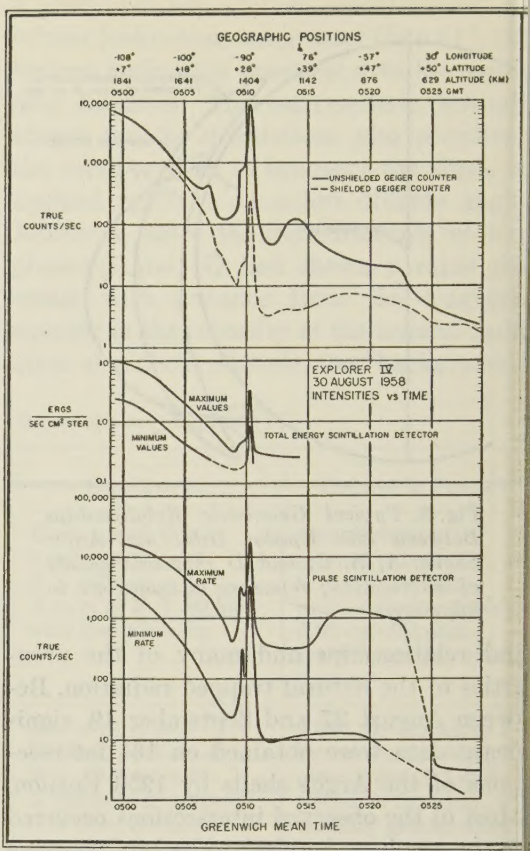

Fig. 6. *Comparison of Geiger Counter and Scintillator Records Showing Intersection of Argus Shells by 1958 Epsilon on August 30, 1958.*

showing the decaying peak (0446 UT) o the Argus I radiation and the fresh pea (0449 UT) resulting from the Argus I detonation. Plots of the reduced and cor rected data from all four detectors for a intersection on August 30 are shown in Fig ure 6.

The angular motion of the satellite as rolled and tumbled through the electro shell, apparent in the instrumental record was advantageous for the measurement o angular distributions of the Argus electron These distributions, as observed near th mirror points, were found to form disc-lik patterns (Fig. 1), as previously suggeste by the magnetic-trapping theory and as ob served extensively in studies of the natur radiation.

In each set of observations, the output of each detector was converted either to true counting rate (channels 1, 2, 3, and 5) or to absolute directional energy flux (channel 4), using pre-flight calibration data. From the corrected plots, estimates were made of net intensity of Argus electrons above background; "time width" of the Argus peak between points of half-maximum intensity and between points of 1/10 maximum intensity; local maximum and minimum intensities near the center of the peak; and time of occurrence of the center of the peak. Then, using the ephemeris of 1958 Epsilon, tabulations were made of the latitude, longitude, and altitude of the center of the peak, and of the geometric thickness of the shell at half-maximum intensity, measured perpendicular to the shell.

Preliminary Summary of Results: Based on the data collected by 1958 Epsilon during its intersections of the Argus shells, certain preliminary results have been obtained regarding the shells, the nature of the electrons, and the geomagnetic field.

The mean thickness, at half-maximum intensity and measured perpendicular to the shell boundaries, of the Argus I and II shells was about 90 kilometers, and the mean thickness of the Argus III shell was about 150 kilometers. The thickness did *not* depend systematically on elapsed time, (except possibly during the magnetic storm on about September 4; see below), but the measured values show a scattering of about 30%. The investigators assume that the basic shell thickness was determined by the very complex injection situation at and immediately following each detonation. This surmise is supported by rough calculations of the dynamics of the detonations in the earth's magnetic field.

The magnetic shells reached outward about two earth radii from the center of the earth. The leakage of particles from the ends of the shells and by energy loss proceeded at a sufficiently rapid rate so that, in general, diffusion across the boundaries of the shells was too slow by comparison to be observed.

Plots were made in which each observation of the center of each Argus shell (I, II, and III) was projected downward to the surface of the solid earth by use of a simplified model of the geomagnetic field (the eccentric dipole model, in which the magnetic axis does not correspond to the geographic axis). The three resulting loci of points, interlaced in time, are notably smooth and regular, suggesting positional stability of the shells during the observing period. It was concluded that the shells could not have drifted in latitude by more than about 0.03° per day (about 2 kilometers per day at a height of 1500 kilometers) without having resulted in a "ripple" in the implied geomagnetic field contour not supported by other data.

The disc-like character of the angular distribution of the trapped electrons, and the angular thickness of $\pm$ 20° or less, show that at the relatively low observational altitudes most particles measured had turning points (or mirror points) not more than a few hundred kilometers below the locations of the observations. This is quite reasonable in terms of the basic dynamics of magnetic trapping.

The maximum observed intensity at the center of the shell multiplied by the thickness of the shell at half-maximum intensity has been taken as a measure of the total intensity of trapped particles (within the range of the detector used). Several preliminary plots of this quantity against elapsed time were made for two different possible positions in the geomagnetic field. Examination of these plots, and application of a theory by Ernest C. Ray of SUI on the loss mechanism for particles trapped in the magnetic field, permits estimates of the time-decay of the intensity of the trapped radiation. These estimates pertain to an effective electron energy of 3.5 mev. Ray computed the effective atmospheric density, for an altitude of 1000 kilometers, that

would be required to reduce the radiation intensity as rapidly as observed. He found this density to be least 10 times as great as that reached by extrapolation from an atmospheric model derived by Robert Jastrow from studies of atmospheric drag on satellites. The SUI workers believe it is possible that atmospheric density is anomalously high in the region of the Argus shells, which occurred in the "slot" between the two zones of trapped natural radiation (Fig. 2).

An alternative speculation is that the rapid decay was caused, in part at least, by "magnetic diffusion" owing to small-scale and perhaps time-dependent irregularities of the geomagnetic field. Investigation of this possibility is in process, using the results obtained from all four detectors, which were designed for different effective particle energies.

The gross decay rate is presumably a composite of atmospheric and magnetic effects.

A discontinuously rapid drop in intensity of the Argus I and Argus II radiation on about September 4 suggests that a very large magnetic storm on that date may have caused great enhancement of the rate of loss of stored particles. Also, the Argus II shell appears to have thickened significantly during this period.

The 1958 Epsilon observations permit estimation of the total number of trapped Argus electrons having turning points below the highest altitude of observation. This estimate, made as of zero elapsed time, serves to supply a lower limit to the fraction of electrons effectively injected into the geomagnetic field, since the nominal yield of the injection and the nominal energy spectrum of the electrons are known.

When the product CWt (maximum intensity at the center of the shell × thickness × time) is plotted against the strength of the magnetic field in the region occupied by the shell, it can be seen that there is an increase in the density of turning points with increasing altitude (i.e., with decreasing field strength). It is therefore evident that injection of the longer-lived electrons occurred largely at altitudes much greater than that of the detonations.

As a result of observations of satellite 1958 Epsilon, the geometric form of the Argus shells is known to a precision of about ± 10 kilometers with respect to the earth. Hence, these experiments provide a significant new method for the harmonic analysis of the general geomagnetic field. Although this analysis is not yet complete, it is already clear that at least the dipole and quadrupole terms of the magnetic field can now be determined with useful accuracy.

Optical, Radio, and Magnetic Observations

Because it was expected that the Argus detonations might result in optical, radio and magnetic effects that could be observed from ground level, the Stanford Research Institute and the Air Force Cambridge Research Center cooperated in a program to measure these effects. The techniques used and some of the results of these experiments are described below.

Aurora: The auroral luminescence resulting from the Argus detonations was observed at both the detonation site and the conjugate point in the northern hemisphere by visual observers, all-sky cameras and other photographic methods, and by radar. In addition, photometers and interference filters were used to study the spectrum of the artificial auroras.

In the detonation area, all three events were accompanied by colorful auroras elongated along a line intersecting the magnetic meridian at an angle of 10°. Photometric records were obtained for each event at the 5577 A and 3914 A wavelengths of the auroral spectrum. (The former is the green line of atomic oxygen and the latter is one of the violet lines of nitrogen.) The ratio of atomic oxygen to nitrogen, about 10:1 for

the third Argus event, was much higher than that usually observed in natural auroras.

The investigators assume that the auroral effect was caused mainly by the strong excitation by fission products of oxygen and nitrogen at the 100-kilometer level in the earth's atmosphere. The photometric records also serve as a check on the detonation time.

In the conjugate area, near the Azores Islands, only one doubtful sighting was made after Argus I and none was made after Argus II. After the third detonation, however, a brilliant auroral display was observed by many members of the crew of the *USS Albemarle* and by civilian scientists aboard. Distances to the conjugate aurora resulting from Argus III, estimated by observers aboard the *Albemarle*, correspond to auroral heights of about 240–565 kilometers. Visual estimates of its duration ranged from about 5 to about 30 minutes.

Radar echoes were returned from all three of the auroras in the detonation area and from auroras accompanying Argus I and III at the conjugate point. In the detonation area the echoes appeared within seconds after the burst. In one case, these echoes were observed for five hours. In the conjugate area, echoes appeared somewhat later, but still within a minute of the burst, and lasted in one case for an hour and 15 minutes. The radar observations in the conjugate region agree approximately with the auroral height estimates based on the visual observations, and, in combination with the visual observations, located the conjugate point within about 100 kilometers of the theoretically expected location.

Magnetic and Electromagnetic Studies: It was expected that a detonation of the Argus type would cause a shock wave in the atmosphere which would be propagated as a hydromagnetic wave, or Alfven wave, along the magnetic line of force. This effect would be detectable on the ground by very-low-frequency (VLF) equipment or by magnetometers. A change in the magnetic field might result from the hydromagnetic wave or from an electric current in the atmosphere.

Several types of equipment were available in the Azores to monitor these effects. Extremely-low-frequency (ELF) instrumentation (0.3 to 30 cycles/sec) was set up to measure changes in the magnetic field. Also used were a heliflux magnetometer and a variable-mu magnetometer to measure the static field. Regular magnetic stations, as well as IGY aurora and air glow stations, were also available to observe detonation effects. Similar equipment, with the exception of the ELF apparatus, was installed on ships in the detonation area.

The ELF receiver in the conjugate area obtained results for the second and third detonations, but not for the first. (Argus I took place during a geomagnetic disturbance accompanied by unusually severe radio blackout. Moreover, the magnetic lines of force within which Argus I took place, and along which these effects presumably would be propagated, may have passed through or near the lower of the Van Allen radiation regions.)

ELF signals received after the Argus II and III detonations were unmistakably distinguishable from background electromagnetic effects. Harmonic analyses indicated signal components between about ½ and 2 cycles/second. Estimates of changes in amplitude of the various magnetic-field components ranged from about 1/25 to 3/2 gamma, with the largest changes generally occurring in the east-west component of the field and the smallest in the vertical component.

The ground speed of propagation of a strong disturbance (at plus 42 seconds) from the detonation point was about 700 km/sec. If it is assumed that the disturbance followed the magnetic line through the detonation point, its average speed along the line of force would be about 2000 km/sec.

A magnetic detector in the launch area recorded an initial one-second-pulse signal of about one cycle/sec for Argus III with a strength of more than 10 gammas, followed by longer-period pulses. The total duration, with irregular fluctuation, was about 1½ minutes.

Radio Propagation: Variations in propagation characteristics of radio waves in the very low frequency (VLF) range—300 cycles/sec to 30 kilocycles/sec—have for many years been recognized as sensitive indicators of lower-ionosphere conditions (below about 100 kilometers). The VLF signals can be enhanced by increased ionization at the normal heights of reflection of the radio waves; on the other hand, if ionization is increased at lower levels, where atmospheric density is greater, absorption results and signal strength is reduced.

For the Argus experiments, VLF equipment similar to that used during the IGY for whistler studies (see *Bulletin No. 6*) was designed, constructed, and installed by the Stanford University Radio Propagation Laboratory. Recordings were made with this equipment in the launch area, at several locations in the conjugate area, and at Stanford University, California.

Of particular interest were recordings made in the Azores and in Spain of signals at a frequency of 19.6 kilocycles/sec from station GBZ in England. These recordings showed abrupt decreases in signal strength of 6-12 decibels following Argus II and III. Recordings made at Stanford University of signals from stations NPG in Seattle (18.6 kilocycles/sec) and NDT in Japan (17.1 kilocycles/sec), on the other hand, showed slight increases in signal strength for some minutes following Argus II and III.

A possible explanation for the observations in the conjugate area is that electrons scattered from the magnetic shells, as well as the ionized debris itself, may have penetrated to low altitudes, increasing the ionization in the lower ionosphere and producing absorption. In the Pacific, far removed from the original injection region, the enhancement of signal strength may indicate increased ionization at higher levels above the earth.

Radio Noise: As part of the Argus measurements, three riometer stations were operated near the conjugate region at frequencies of 30, 60, and 120 megacycles/sec and one was operated near the launch area at 30 megacycles/sec. (The riometer is designed for sensitive routine measurement of ionospheric absorption by monitoring the power level of cosmic noise propagated through the ionosphere.)

Although the perturbation of the ionosphere by the Argus detonations was sufficient to reduce, by absorption, the strength of VLF signals (see above), it was not large enough or widespread enough after any of the three Argus detonations to be detected by the riometers.

Another purpose of the riometer network was to provide a sensitive measure of radio noise that might be generated by electrons trapped in the Argus shells. Noise from this source was not detected, and, on the basis of particle-counting data from 1958 Epsilon during the Argus Experiment and of comparison of electron density in the Argus shells with counting rates in the Van Allen regions, it is now believed that this radio noise should, in fact, have been below the detectable level. However, the experiment showed that such radio noise information might reasonably be extracted, in the future, by careful radio astronomy methods.

Jason Rocket Observations

The "Jason" project, conducted by the Air Force Special Weapons Center, consisted of the launching of 19 high-altitude rockets carrying instrumentation to measure the electron flux of the Argus shells. The rockets were sent to altitudes of about 800 kilometers from Cape Canaveral, Florida, Wallops Island, Virginia, and Ramey Air Force Base, Puerto Rico. The

sites were chosen to provide sufficient latitudinal coverage to assure interception of the shells. The instrumentation in each rocket consisted of eight Geiger-Mueller counters with various amounts of shielding to provide an energy scale and various orientations to provide directional information. Data were telemetered to ground stations. Thirteen successful flights were made, one for pre-Argus background data, two following Argus I, and 10 following Argus II.

Only limited data were obtained from the Argus I flights, but much information resulted from the flights following Argus II. Rockets launched southward from Wallops Island observed a narrow region in which counting rates were very high—initially, 100,000 times normal. The rockets penetrated the Argus II shell at altitudes of about 320 to 485 kilometers, and the shell was observed to be about 20 kilometers thick in this region. Increases in radiation level were observed about 700 kilometers to the north and to the south. Both the width and the position of the shell remained constant (± 8 kilometers) throughout the 100-hour observation period. This extreme constancy, while the electrons traveled from north to south more than 1,000,000 times and drifted around the world more than 100 times, verifies many important hypotheses about the earth's magnetic field and the character of space as far out as one earth radius from the surface.

The intensity of trapped electrons in the shell was observed to be approximately inversely proportional to the time from the burst. This is consistent with the theory that the trapped electrons are lost predominantly through scattering in the atmosphere near the mirror points.

Measurements of angular distribution of the electron flux, based on determination of the orientations of the rocket instrumentation by analyzing telemetry signal-strength records, show that the flux was confined to a plane very nearly perpendicular to the lines of force of the magnetic field.

Conclusions

A great variety of measurements of the magnetically trapped radiation from the Argus detonations were made by special instrumentation included in the payload of IGY satellite 1958 Epsilon and by rockets and ground-based equipment employed by various agencies. Preliminary analyses have confirmed the theory of trapping of radiation by the magnetic field of the earth and have supplied new information about the configuration and some of the characteristics of the magnetic field. Data gained by this controlled experiment, in which many of the factors were known, may also provide an improved basis for understanding the mechanics of the natural trapping of charged particles in the Van Allen radiation regions, and of related phenomena such as the aurora.

Oversnow Traverses from IGY Little America Station

The following material was prepared by Albert P. Crary, leader of the traverses described and Station Scientific Leader at Little America Station during 1956–57 and 1957–58.

Three oversnow traverses were made inland from Little America Station during the International Geophysical Year. (Figure 7 shows the routes of these three traverses and of others made during the IGY.)

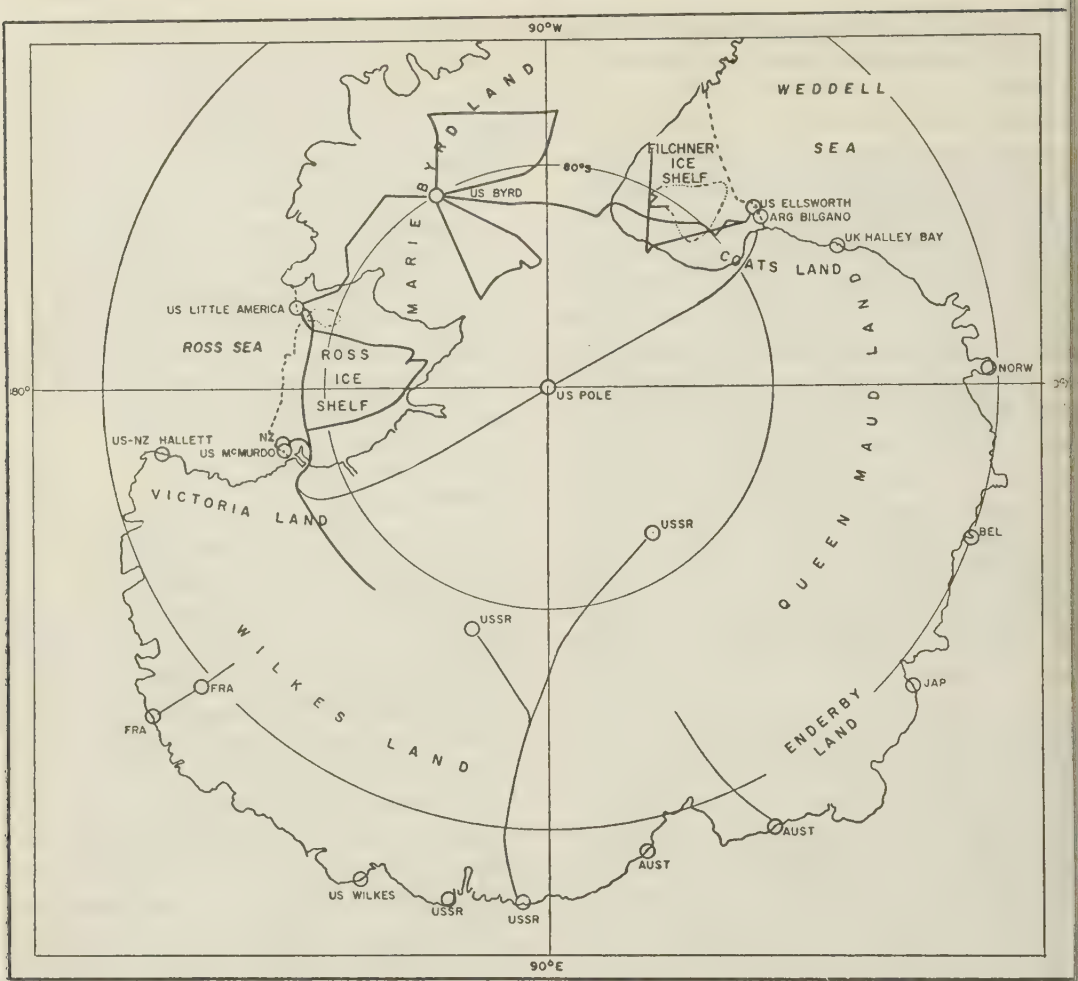

FIG. 7. *Antarctic Traverses During IGY. Treated in this report are those made from US-IGY Little America Station on the Ross Ice Shelf during 1957–58, and in the following year from Little America across the Ross Ice Shelf up the Skelton Glacier and along the Victoria Land Plateau.*

The Ross Ice Shelf Traverse, from October 24, 1957, to February 13, 1958, covered a total of about 1225 nautical miles. (A preliminary description of this traverse is given in *Bulletin No. 10.*)

The Byrd Tractor Trail Traverse was made from March 25 to April 10, 1958. The party traveled along the Little America-Byrd Station tractor trail for 140 nautical miles, to a point close to the junction between the floating and grounded ice.

The Victoria Land Traverse started on October 15, 1958, at Little America Station and ended January 31, 1959, at Scott Base (NZ) on Ross Island in McMurdo Sound. The first part of this journey duplicated the first leg of the Ross Ice Shelf Traverse of the previous year. On this stage, a few additional observations were made in some areas where the 1957–58 water depth and gravity readings departed from computed norms. The standard program of closely spaced observations, including data needed for glacial regime studies, started as the party left the earlier route and headed west to the Skelton Inlet, a few miles south of the Minna Bluff-Mount Discovery peninsula.

A month was spent moving from the shelf ice up the Skelton Inlet and the Skelton Glacier to the Victoria Land plateau. From the top of the plateau at the head of the Skelton Glacier, the traverse party traveled due west. It followed a line a few miles south of 78°S for about 350 nautical miles to 131.5°E. The party then returned along the same route, making stops on the Skelton Glacier and on the western Ross Ice Shelf to remeasure snow accumulation and ice movement at stakes installed on the outward journey. From Minna Bluff to Scott Base a detailed seismic-sounding and ice-movement program was undertaken.

A large portion of the data taken on these traverses is still in the process of reduction and analysis. This report describes some preliminary results of the studies on the Ross Ice Shelf and in Victoria Land.

Ross Ice Shelf

Study of the Ross Ice Shelf was included on all three of the traverses. Figure 8 shows tentative ice thicknesses; the elevation of the surface above sea level was generally 1/7 to 1/8 of the ice thickness. The general thickening of the shelf along the southeastern part (upper left in Fig. 8) is indicative of the large contribution to the nourishment of the shelf made by the southwestern part of Marie Byrd Land and the polar plateau, as compared with that of the glaciers along the western part of the shelf. Near the junction of the floating and grounded ice in the Skelton Inlet (lower right in Fig. 8), floating ice is nearly 1000 meters (approximately 3280 feet) thick.

Figure 9 gives preliminary findings on water depths, with some data from US Navy Hydrographic Office charts added for the waters off the barrier edge. The deep waters around the periphery of the shelf, and the particularly deep sounding due south of Mount Discovery, are noteworthy. A few soundings even deeper were made in the Skelton Inlet, a distinct fiord with deep

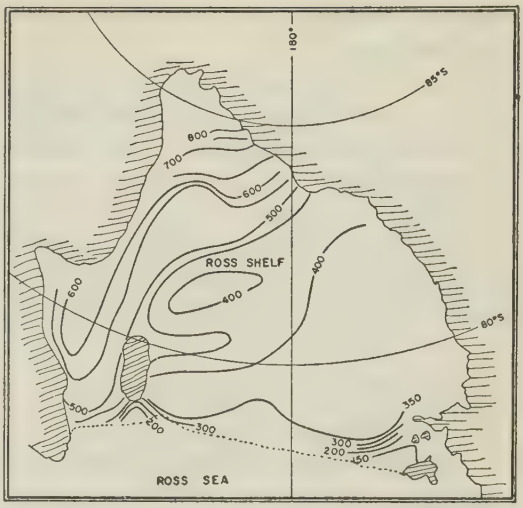

FIG. 8. *Thickness of Ice Shelf in Meters.*

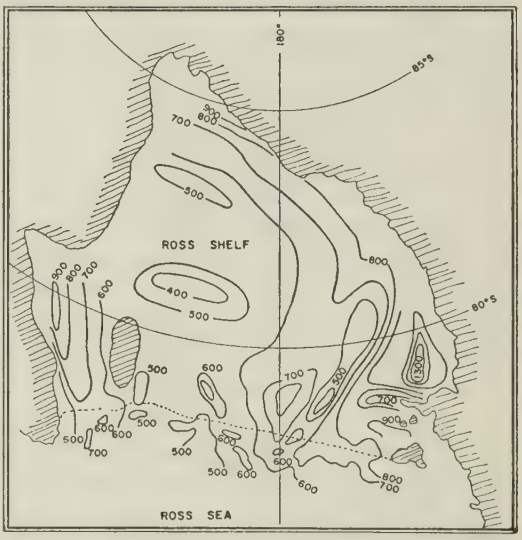

FIG. 9. *Depth of Water Below Sea Level in Meters.*

water for considerable distances into the mountain area.

Victoria Land

The Victoria Land plateau area proved more difficult to explore by seismic soundings than the low-elevation shelf areas. Deeper holes for explosives and various recording techniques were tried and to some extent were successful. To supplement the

reflection soundings, several refraction profiles were made.

During the 350 nautical miles traveled into the plateau area, no mountain ranges or nunataks were observed. The surface was characterized by quite rough sastrugi (see *Bulletin No. 22*).

Figure 10A shows the profile of the 1958–59 traverse from the Ross Ice Shelf through the Skelton inlet and glacier and into the plateau area, giving approximate surface elevations and ice thicknesses. At the western end of the line, near 130°E, the elevation of the surface was found to be about 2850 meters, comparable with the elevation at the South Pole Station. It is noted also that the surface elevation rises toward the west. The USSR-IGY Vostok Station, with an elevation of about 3420 meters, lies about 300 nautical miles farther west. This would

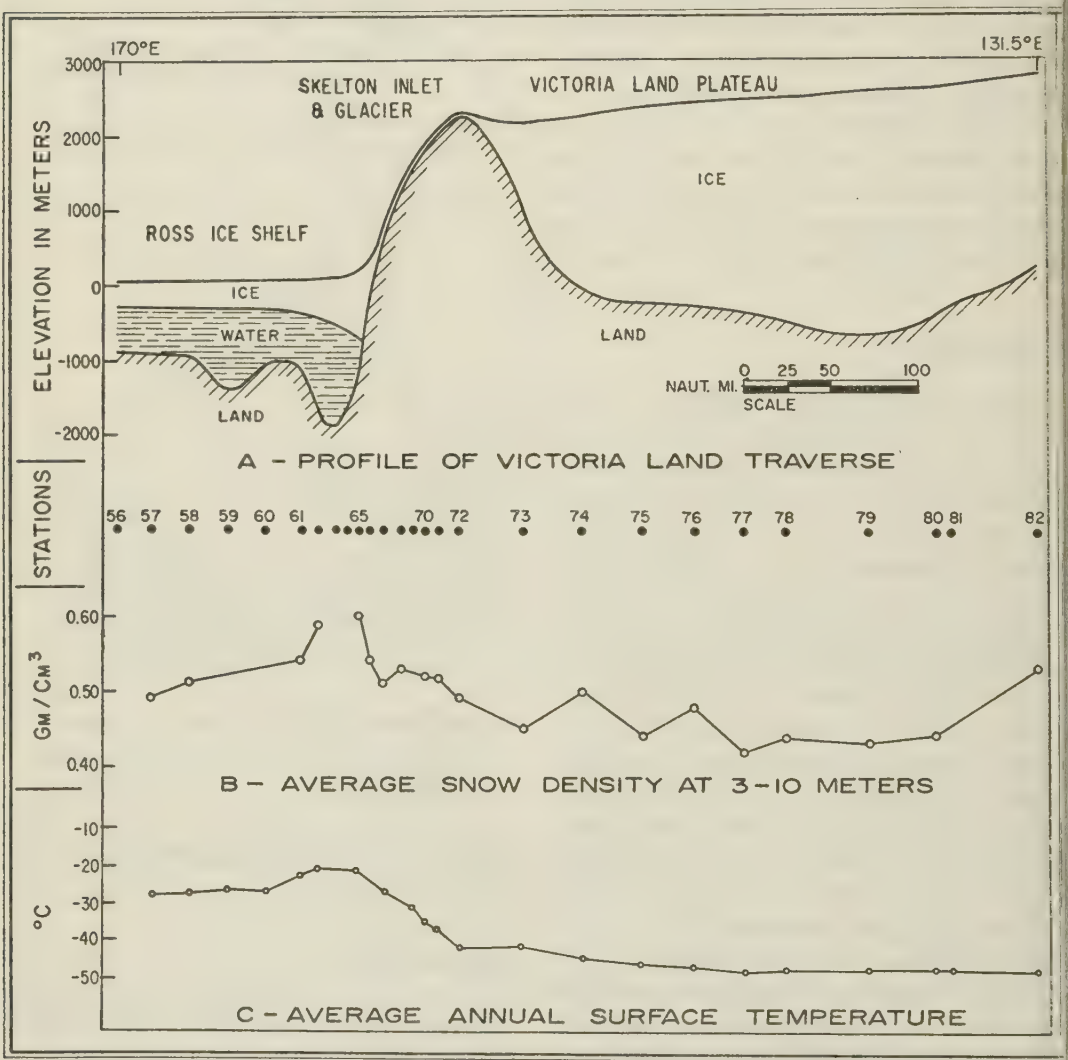

FIG. 10. *Profile from Ross Ice Shelf Westward into Victoria Land Plateau, Showing Surface Elevations, Ice Thickness and Bedrock Topography. Also shown are snow densities and temperatures. The gap in the center segment at Stations 63 and 64 reflects densities greater than 0.8, beyond the scale of the chart. Temperatures were taken at 10-meter depths; experience shows that these approximate average annual air temperatures just above the snow surface.*

require an average climb of 2 meters per nautical mile, or somewhat less than the slope observed at the end of the traverse.

Immediately west of the Skelton Glacier area, surface elevations drop about 150 meters, making it appear likely that drainage of plateau ice through the mountains along the western border of the Ross Ice Shelf is not significant. This is further substantiated by shelf thicknesses shown in Figure 8.

In Figure 10B are plotted the average snow densities between depths of 3 and 10 meters, as found in cores obtained during drilling of seismic shot holes. A significant density increase occurred in the Skelton Glacier area. At Stations 63 and 64, the surface consisted of hard, blue ice with a density greater than 0.8. On the plateau, the densities were generally low but quite erratic, an abnormally high value of .53 being found at the westernmost station.

Figure 10C gives the temperatures at a depth of 10 meters for the profile from the Ross Ice Shelf to the plateau area. (These are quite close to the average annual air temperatures near the snow surface; hence, they represent general climatic conditions.) From an average of —28°C (about —18°F) on the shelf, temperatures fell to —48°C (about —54°F) on the western part of the plateau line. This is not much different from the —50°C at the South Pole Station, more than 700 nautical miles farther south. The rise in temperature in the Skelton Inlet may reflect higher summer temperatures owing to exposed rock areas, or higher winter temperatures resulting from high average down-glacier wind speeds.

During the descent of the Skelton Glacier on the return trip, detailed altimetry was obtained by reading one of the altimeters at short time intervals while the vehicle was in motion. The figures were adjusted to

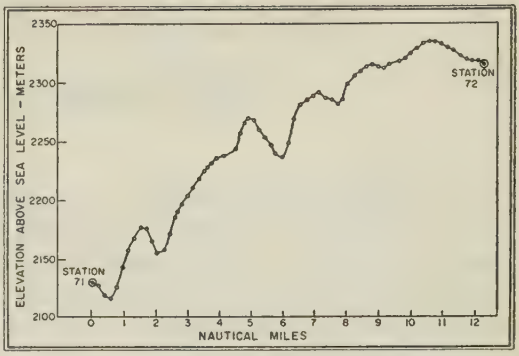

FIG. 11. *Elevations Near Top of Skelton Glacier. The altimetry readings on which these are based were taken during the descent of the glacier on the return trip.*

elevations at the major stations determined from multiple altimetry and transit surveys. Figure 11 shows part of the results of this study near the top of the Skelton Glacier, where the long ridges and troughs were quite pronounced.

An estimate of the average annual snow accumulation on the plateau is not yet available, and preliminary analyses indicate that snow characteristics as obtained from the pit studies may be quite difficult to interpret. If snow accumulation is small and wind erosion high, the changes in oxygen-isotope ratio with season may also be poorly defined. (See *Bulletin No. 21* for a discussion of oxygen-isotope methods.) For reliable information on accumulation patterns, it may be necessary to await future repeat observations of the snow stakes placed on the plateau during this traverse.

Future traverse parties from Scott Base will continue the exploration on the Victoria Land plateau, possibly tying in with French traverse work to the northwest and the USSR work to the west. The combined results will assist in the compilation of a comprehensive picture of this part of the Antarctic continent.

Hydrobiological Measurements on IGY Drifting Station Bravo

The following report is based on material supplied by Spencer Apollonio, Yale University. The IGY work it describes was supported by the Air Force Cambridge Research Center and the Woods Hole Oceanographic Institution.

As part of the IGY program, measurements were made at IGY Drifting Station Bravo, on Fletcher's Ice Island (T-3), to determine the level of primary organic productivity in the Arctic Ocean.

The productivity of the smaller plant and animal life in the sea is important in assessing potential marine food supplies, since fish resources depend on these lower forms of marine life for sustenance. Organic productivity can be determined by measuring the amount of photosynthesis taking place and the concentrations of chlorophyll in the water. The Station Bravo productivity studies included both of these measurements, and also determination of nutrient concentrations.

When the measurements were begun, there was little doubt that productivity would be low because of the unfavorable conditions for life in the Arctic Ocean. Nevertheless, it was hoped that the level could be determined quantitatively, and to some extent this has been achieved, although difficult working conditions made it impossible to accomplish some of the planned measurements.

Complete analysis of the plant and animal collections will take considerable time and the results will be reported later. Advice and assistance were received from J. H. Ryther, C. S. Yentsch, R. A. Vaccaro, and N. W. Corwin. J. A. Murray, Jr. supplied radiation data from Station Bravo observations.

Environmental Conditions

The drift of Station Bravo during thi study was along the edge of the continenta shelf, within 100 miles of the north coas of the Canadian Arctic Archipelago (se *Bulletin No. 24*). The ice island itself is es timated to be about 160 feet thick. Withi a mile of the island the pack-ice thickness determined from numerous corings, range from 10 to 30 feet in an apparently irregu lar manner. Beyond a mile from the island' edge, the pack ice was extremely broke and no thickness measurements were made

The hydrobiological sampling site wa on the pack ice about 500 feet from th edge of the island. Observations were mad through a hole 14 feet in depth.

Hard, windpacked snow covers the ic from late August until about the first week of July. The melt curve for the snow cove of 1957 is shown in Fig. 12. It is probabl that during the summer the snow cover i the greatest limiting factor on productivity in the ocean. No light-extinction coefficient are available for the various states of th snow. In April, however, under bright, clea conditions, light penetration was not detect able by a photocell and micro-ammeter a a depth of four inches below the snow surface.

During the summer snow-free period, ex tensive melt-water lakes cover the pack ice Preliminary evidence from IGY Driftin Station Alpha (on an ice floe elsewhere i the Arctic Ocean) indicates that these lake may act as lenses, concentrating ligh through the ice and increasing organic pro ductivity below them.

Through the summer of 1957, a lea (long, narrow passage in pack ice) abou 50 feet wide and 3–4 miles long persiste at a distance of 1½ miles from the samplin

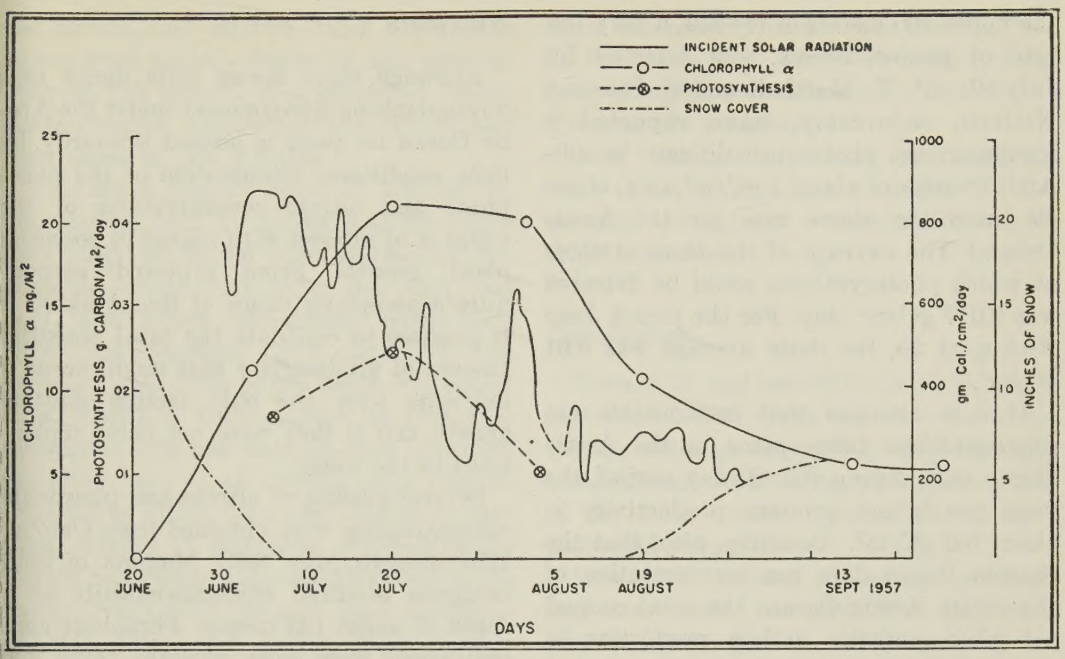

FIG. 12. *Average Thickness of Snow Cover and Average Amounts of Incident Solar Radiation, Photosynthesis, and Chlorophyll α, Summer 1957, at IGY Drifting.*

site. The possible existence of other leads close to the island, or the amount of open water in that part of the ocean, is not known. Visual observations on five aircraft flights to Station Bravo, however, suggest that open water occupies less than 1% of this area in summer. Hence, the effect of ice-free, open water on the results of this study can be considered negligible.

It is significant that patches of diatoms (microscopic algae) frozen in pack ice in the Arctic Ocean, mentioned by Nansen in 1902, and by others, were never noticed in the vicinity of Station Bravo. It is also remarkable that invertebrate animals were never seen, either in the sampling hole or in the lead. Efforts to trap amphipods (small crustaceans) by methods that had proved successful in other parts of the Arctic Ocean were fruitless. One seal was seen in the lead.

Photosynthesis Measurements

During June, July, and August 1957, net photosynthesis (photosynthesis minus respiration) of the phytoplankton—floating plant life—was measured at five locations by the carbon-14 method. (It seems obvious that photosynthetic carbon assimilation is impossible during the winter in higher Arctic latitudes owing to the lack of light during the six-month-long Arctic night.) Water samples were collected by non-metallic samplers. One milliliter of $C^{14}O_3^=$ (activity 2,400,000 counts/min) was added to each sample in a 150-milliliter glass-stoppered bottle and the bottle resuspended for 24 hours at the depth from which the sample was taken. The samples then were filtered through millipore filters; these filters were preserved and the amount of activity later determined at the Woods Hole Oceanographic Institution.

For samples taken at the first two locations, on June 12 and 21, no photosynthesis could be detected by this sensitive technique. Photosynthesis was detected at the other three locations, on July 6, July 12, and August 7.

A maximum rate of 0.024 $gC/m^2/day$ in

the upper 100 meters of the sea, a very low rate of photosynthesis, was detected for July 21. (P. T. Marshall and E. Steeman Nielsen, separately, have reported a maximum net photosynthetic rate in sub-Arctic waters of about 1 gC/m^2/day, about 40 times the above rate for the Arctic Ocean.) The average of the three stations at which photosynthesis could be detected was 0.017 gC/m^2/day. For the period June 20-August 20, the daily average was 0.01 gC/m^2.

If it is assumed that measureable net photosynthesis takes place in the Arctic Ocean only during this 60-day period, the total yearly net primary productivity is about 0.6 gC/m^2. Assuming, also, that the Station Bravo data are representative of the entire Arctic Ocean, the total annual net photosynthetic carbon production is computed at 8.45×10^6 tons. The annual net production for all oceans has been estimated by Steeman Nielsen and E. Aabye Jensen at 1.5×10^{10} tons.

Chlorophyll Concentrations

Water samples were collected and filtered through millipore filters; these filters were preserved and analyzed at Woods Hole for chlorophyll concentrations. The maximum of 0.37 mg/m^3 on August 5, 1957, measured just under the ice, compares closely with the August maximum of 0.4 mg/m^3 found two decades earlier in the upper 20 meters of the Arctic Ocean by the Soviet investigator Shirshov.

It appears from comparisons with similar studies in other Arctic areas that ice-free Arctic waters may develop a maximum chlorophyll concentration as much as 13 times that found in the ice-covered Arctic Ocean. The average concentration in these ice-free waters during one season may vary from 2 to 5 times that of the ice-covered areas. It is significant, however, that even at a depth of 500 meters in the Station Bravo area some chlorophyll could be detected during the summer.

Nutrients

Although there seems little doubt tha phytoplankton development under the Arc tic Ocean ice pack is limited primarily b light conditions, examination of the phos phate and nitrate concentrations of th water is of interest with regard to potentia plant growth. From expected carbon nitrate-phosphate ratios of the plankton is possible to calculate the total potentia amount of productivity that might occur nutrients were the only factors limitin growth and if they were not being replen ished to the water.

Several profiles of nitrate and phosphat concentrations were obtained from Octobe 1957 through May 1958. Maxima of bot nutrients occurred characteristically at depth of about 125 meters. Phosphate con centrations were quite constant below 20 meters, but nitrate concentrations wer more variable below this depth. Minimu values of both nitrates and phosphates wer

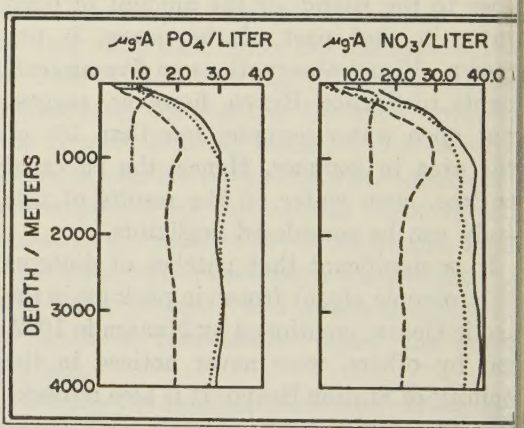

FIG. 13. *Phosphate and Nitrate Concentrations in the Arctic Ocean (dot-dash line) Compared with Concentrations in the Indian Ocean (solid line), Pacific Ocean (dotted line), and Atlantic Ocean (dashed line). Concentrations are shown in microgram atoms (μg·A) per liter.*

found in the upper few meters, and a times nitrates were not detectable at all i the upper levels. Secondary maxima gen erally existed between depths of 350 an

450 meters, and on two dates the nitrate values were slightly higher in this interval than at 125 meters. The secondary phosphate maxima were much less pronounced than those of the nitrates.

The usual oceanic ratio of nitrogen to phosphorus, 16:1 by atoms, was not regularly observed. In the upper 150 meters, the observed ratios were quite low (5:1 and 9:1), and below 200 meters ratios were higher than expected (17:1 and 27:1). The general distribution of the ratios was somewhat variable. Comparisons of inorganic phosphate data and data on total phosphorus show that at all depths some organic phosphorus exists, dissolved and/or in particles. Figure 13 compares graphically the nitrate and phosphate concentrations of the Arctic Ocean with those of other oceans.

Total phosphorus values from Station Bravo are similar to those reported from the Soviet pre-IGY drifting station, NP-2; data from US-IGY Drifting Station Alpha show the same pattern. (See *Bulletin No. 24* for information about the drift path of Station Alpha and reference to material on its scientific programs.)

Two profiles of nitrate concentrations were taken through the pack ice. No detectable phosphate concentrations were found, however.

Conclusions

From IGY and pre-IGY studies in Arctic and other waters, it appears that the Arctic Ocean, although comprising 1/23 the area of all oceans, contributes only about 1/1000 of the total oceanic production of small plant and animal life.

Even if the paucity of sunlight penetrating the Arctic ice pack did not limit phytoplankton growth, the poverty of the Arctic Ocean in nitrate and phosphate nutrients would still make its productivity level one of the lowest in the world.

IGY Bibliographic Notes

This is the fourteenth of a series of bibliographic notes on IGY programs and findings. The references are selected largely from an IGY bibliography under preparation in the Science and Technology Division of the Library of Congress

IGY Bibliography

The first volume of the International Geophysical Year Bibliography is available from the Publishing and Printing Office, National Academy of Sciences, 2101 Constitution Avenue, N. W., Washington 25, D. C. Price $1.00, postage prepaid. The 64-page volume contains 704 references.

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